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Do smokers devaluate smoking cues after go/no-go training?

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ABSTRACT

Objective: Smoking is one of the leading public health problems worldwide. The inability to quit smoking may be the result of the amplified value of smoking-related cues and inhibitory control deficits. Previous research has shown that pairing substance-related cues with no-go trials in go/no-go training reduces the value of these cues, an effect known as devaluation. The current experiment investigated the devaluation effect of go/no-go training on smoking-related cues, and compared this effect between smokers and nonsmokers.

Design and Main Outcome Measures: 39 smokers and 43 non-smokers were trained to respond immediately to neutral stimuli, but inhibit their reaction when smoking stimuli were presented. Before and after training, participants evaluated smoking and neutral stimuli, where part of these stimuli were subsequently presented in the training, and the other part was not used in training.

Results: Not responding to smoking stimuli in go/no-go training decreased subsequent evaluations of trained smoking stimuli compared to untrained smoking stimuli, thereby replicating food and alcohol studies and extending the devaluation effect to smoking-related cues. This devaluation effect was found for both smokers and non-smokers.

Conclusion: Smoking-related cues can be devaluated in smokers and non-smokers, thereby showing the potential for Go/No-Go training in smoking cessation interventions.

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KEYWORDS
devaluation; go/no-go training; inhibition; smoking behaviour; trans-diagnostic mechanism

Introduction

An important determinant of the onset, development, and maintenance of addiction is impulsivity (De Wit, 2009). Impulsivity is a multidimensional concept that is broadly characterized as an individual's ability to regulate and control impulses and behaviour (De Wit, 2009; MacKillop et al., 2011). Inhibitory control is one facet of impulsivity and is defined as the ability to adaptively suppress or stop behaviour when necessary

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Supplemental data for this article can be accessed at here.

(Smith, Mattick, Jamadar, & Iredale, 2014). A widely used task to measure inhibitory control is the Go/No-Go task. In the Go/No-Go task, participants are asked to press a button when a Go stimulus is shown and withhold their response when a No-Go stimulus is presented. The rate of commission errors to No-Go stimuli (i.e., responding to no-go trials) is used as an index of inhibitory control. A recent meta-analysis has shown that poor inhibitory control is related to the abuse of several substances, such as cigarettes, cocaine, and MDMA (Smith et al., 2014), and is also related to behavioural addictions, such as excessive internet use and food intake (Lavagnino, Arnone, Cao, Soares, & Selvaraj, 2016; Smith et al., 2014).

The accumulating evidence for inhibitory control as a trans-diagnostic mechanism underlying several problematic behaviours has prompted studies that examine whether inhibitory control could be strengthened through training. In these training paradigms, which are frequently modified versions of the Go/No-Go task, participants are trained to respond immediately to a neutral stimulus, but inhibit or stop the reaction when a substance-related stimulus is presented (Houben, Nederkoorn, Wiers, & Jansen, 2011). So far, three meta-analyses have shown significant effects of Go/No-Go (GNG) training on either alcohol or food intake, with medium effect sizes (Allom, Mullan, & Hagger, 2016; Jones et al., 2016; Turton, Bruidegom, Cardi, Hirsch, & Treasure, 2016). Thus, GNG training paradigms seem to be able to facilitate behaviour change, at least in the short term and perhaps in the long term (Allom et al., 2016; Jones et al., 2016).

While studies continue to be conducted on the effects of GNG training for food or alcohol abuse, surprisingly, training effects on other addictions or problematic behaviours, such as smoking behaviours, have received little attention. Nevertheless, several studies demonstrate that individuals who smoke often have poorer control over their impulses than those who do not smoke (Luijten, Littel, & Franken, 2011; Smith et al., 2014). Smoking is one of the leading public health problems in the world, killing each year about six million people worldwide (WHO, 2016). Rates of decline for cigarette smoking among youth have slowed, stalled or even slightly increased in the last decade (CBS, 2016; 2017; Gagné, & Veenstra, 2017; Lugo et al., 2017; U.S. Department of Health and Human Services, 2012). It is crucial to invest in research that targets the mechanisms needed to be changed to help these individuals quit smoking. To our knowledge, however, only one study exists that tested the effect of GNG training in the context of smoking (Adams, Mokrysz, Attwood, & Munafò, 2017). The GNG training in this study, did not strengthen inhibitory control or decrease cigarette use among smokers. However, there was weak evidence that GNG training enhanced the ability to resist smoking (Adams et al., 2017).

While behaviour change is the ultimate outcome to be pursued, it is nevertheless essential to understand how and why GNG training may result in behavioural change. That is, we need to examine the underlying mechanism that leads from training inhibitory control to behaviour change. A first theory concerning the underlying mechanism of change assumes that GNG training strengthens top-down control (i.e., strengthening of prefrontal control areas over more automatic subcortical areas), thereby directly improving the ability to resist impulses toward substance-related stimuli (e.g., Houben & Jansen, 2011; Verbruggen & Logan, 2008). However, this assumption has only been tested once by including inhibitory control as an outcome measure with a pre-test/post-test design, with no effects of GNG training on top-down inhibitory control (Adams et al., 2017). Instead, many studies have reported the change in inhibitory control accuracy (commission errors) over the course of training as supporting evidence for this first account (Jones, Hardman, Lawrence, & Field, 2017; Veling, Lawrence, Chen, Van Koningsbruggen, & Holland, 2017). Yet, improvements in inhibitory control accuracy over multiple training sessions could result from learning stimulus-stop contingencies instead of the strengthening of top-down control (Verbruggen, Best, Bowditch, Stevens, & McLaren, 2014; Veling et al., 2017). This alternative bottom-up account hypothesizes that No-Go stimuli trigger inhibition in a stimulus driven way, creating an automatic 'learned reflex' (Veling et al., 2017). Thus, at this point there is hardly any evidence that GNG training results in the strengthening of top-down control.

An alternative theory, the Behaviour Stimulus Interaction (BSI) theory, proposes that GNG training decreases perceived attractiveness of appetitive stimuli, such as substance related stimuli, an effect also known as 'devaluation' (Chen, Veling, Dijksterhuis, & Holland, 2016; Veling, Holland, & van Knippenberg, 2008). According to the BSI theory, when appetitive stimuli are presented on the No-Go trials, participants need to engage in response inhibition to inhibit their approach responses. The approach tendency and the response inhibition lead to a response conflict, and the negative connotation of conflict (Dreisbach & Fischer, 2015) is then attached to the originally appetitive stimuli, making them less attractive. Other work suggests an inherent relation between punishment and No-Go responses, which may also explain devaluation of No-Go stimuli (Guitart-Masip, Duzel, Dolan, & Dayan, 2014). Decreased perceived attractiveness of substance-related stimuli may weaken impulses toward these stimuli, thereby making individuals less likely to approach substance-related stimuli and better able to inhibit their responses (Veling et al., 2008; Veling, van Koningsbruggen, Aarts, & Stroebe, 2014).

Several studies have shown that repeated pairing of food or alcohol stimuli with No-Go cues in single training sessions resulted in lower evaluations of these food (Chen et al., 2016; Lawrence, O'Sullivan, et al., 2015; Veling et al., 2008; Veling, Aarts, & Stroebe, 2013a, Veling et al., 2013b) and alcohol (Houben et al., 2011; Houben, Havermans, Nederkoorn, & Jansen, 2012) stimuli. However, in a meta-analysis by Jones et al. (2016), no effect of repeated inhibition on evaluation of food or alcohol stimuli was found. Important to note though, the studies that found significant effects of GNG training on evaluations used explicit measures to assess stimulus devaluation, whereas almost all studies included in Jones' meta-analysis used implicit methods for measuring stimulus devaluation (e.g., Implicit Association Tasks; Greenwald, McGhee, & Schwartz, 1998). The one study conducted in smokers did not include an evaluation task to examine the devaluation effect (Adams et al., 2017). Altogether, support for the BSI theory in food and alcohol studies is mixed due to different measurement methods, though possibly promising, and at this point no evidence for the BSI exists regarding smoking behaviour.

In the current study we aimed to extend the devaluation effect induced by GNG training to the context of smoking. In the current GNG training, the No-Go condition solely consisted of smoking pictures and the Go condition of neutral pictures, to induce devaluation of the smoking pictures. Before and after the GNG training, participants evaluated pictures that were trained in the GNG training (i.e., trained pictures) and pictures that were not shown in the training (i.e., untrained pictures). In line with previous work (Chen et al., 2016), lower evaluations of trained compared to untrained pictures are interpreted as evidence for devaluation. From an intervention perspective, one would hope for generalization from trained to untrained stimuli, as that would indicate a possible transfer from training to participants' real-world environment. Because this was the first study testing a GNG training in smokers and we changed already some factors in the training design compared to the previous studies, we decided to adhere to the original definition by Chen et al. (2016).

Note that in contrast to most food or alcohol studies, we did not include smoking pictures on Go trials, because this may sometimes increase evaluations of these Go pictures (Chen et al., 2016), which we considered ethically unsound. Besides ethical considerations, this design choice was also based on the clinical impact we ultimately want to make with this training. If we eventually want to develop a GNG training that can train individuals to quit smoking, it is important that the smoking pictures are always related to No-Go cues. In addition to smokers, we also included a group of non-smokers to explore whether devaluation can also be attained in this group and thus whether a GNG training could possibly serve as prevention tool as well.

We hypothesized a devaluation effect for smoking pictures among smokers. This means, in line with previous work (Chen et al., 2016), that Smoking No-Go pictures will be evaluated less positively after the GNG training than Smoking Untrained pictures. Furthermore, we explored the effects of a GNG training on non-smokers, and we had no strong expectations about whether a devaluation effect would be attained in this group. Finally, it was expected that generally smoking pictures would be evaluated less positive than neutral pictures in both groups (Rehme et al., 2009; Stippekohl et al., 2010). Yet, smoking pictures would be evaluated more positively by smokers than by nonsmokers (Rehme et al., 2009; Stippekohl et al., 2010).

Materials and methods

Participants

Participants were recruited to participate in this experiment through on online recruitment system at Radboud University. To be included in the study, participants had to be (1) either nonsmokers (defined as not smoking at this moment, and never been a daily smoker in the past), or smokers (defined as smoking at least weekly or more); (2) between 18 and 30 years of age; (3) willing to give informed consent. A total of 86 participants took part in the experiment, 42 (48%) were smokers and 44 (52%) were nonsmokers. Based on a meta-analysis by the time of conducting this experiment, the average effect size of GNG training on health outcomes was expected to be Cohen's $d = 0.534$ (Allom, 2014). Power analysis indicated that 40 participants in both groups would be needed to achieve 90% power, using a Repeated Measures Analysis of Variance within subjects design (G*Power; Faul, Erdfelder, Lang, & Buchner, 2007). Four participants were excluded; one of the nonsmoking participants indicated to be a current smoker after all, and one of the smoking participants indicated he had quit.

Two smoking participants were excluded because their Go or No-Go accuracy during the training was three standard deviations below the mean (see Chen et al, 2016; Chen, Veling, Dijksterhuis, & Holland, 2017, where a similar exclusion criterion has been used).

Non-smoking participants ($n = 43$) ranged in age from 18 to 28 ($M = 21.37$, $SD = 2.51$) and 26% were male. Thirty-eight non-smokers (88%) indicated that they had never smoked in their lives. The remaining 12% non-smokers had smoked before, with the number of cigarettes ever smoked ranging from 1 to 75 ($M = 19$, $SD = 31.84$). None of the non-smokers indicated ever having smoked on a daily basis. The smoking participants ($n = 39$) ranged in age from 18 to 29 ($M = 22.36$, SD =3.00) and 31% were male. Smoking participants smoked on at least one day a week ($M = 4.36$, SD =2.22, range =1–7). At smoking days, they smoked at least one cigarette a day ($M = 5.51$, SD =5.12, range =1–25) for at least a year ($M = 5.47$, SD =2.96, range =1–14). Fagerström scores (FTND) were suggestive of low levels of nicotine dependence, $M = 1.15$, SD =2.02, range =0–6 (Heatherton, Kozlowski, Frecker, & Fagerstrom, 1991; Vink, Willemsen, Beem, & Boomsma, 2005). Participants showed low levels of craving at pre-training ($M = 22.00$, SD =11.09, range =10–70) and post-training ($M = 24.90$, SD =12.82, range =10–70). A paired samples t test showed that there was no significant difference between pre- and post-training in craving levels ($t(38) = -2.02$, $p = .05$). Finally, 64% of smokers attempted to quit smoking before, with an average of 1.46 quit attempts ($M = 1.46$, SD =1,94, range =0–10). There were no significant differences between the smoking and non-smoking group in mean age ($t(80) = -1.62$; $p = .109$), sex (X^2 (1, $n = 82$) = .27, $p = .602$) or educational level (X^2 (4, $n = 82$) = .92; $p = .917$). Most participants (over 65%) came from high educational streams.

Materials and measures

FTND

Participants in the smoking group filled out the Dutch version of The Fagerström Test for Nicotine Dependence (FTND; Vink et al., 2005). This is a 6-item questionnaire aiming to assess nicotine dependence. Some items are answered on a 4-point scale, other items are yes (=1) or no (=0) questions. An example item is: "Do you find it difficult to refrain from smoking in places where it is forbidden?". In previous research, the FTND showed acceptable reliability and correlated significantly with number of cigarettes smoked per day in a Dutch sample (Vink et al., 2005). Internal consistency of the FTND items in the present sample of $n = 39$ was acceptable (α =.78).

QSU

The Questionnaire of Smoking Urges (QSU-Brief; Cox, Tiffany, & Christen, 2001; Tiffany & Drobes, 1991) was assessed to measure subjective craving to smoke. The QSU-Brief consists of ten items answered on a 7-point likert scale ranging from "strongly disagree" (=1) to "strongly agree" (=7). An example item is: "I would do almost anything for a cigarette now?". The QSU showed good psychometric properties in a Dutch sample (Littel, Franken, & Muris, 2011). Internal consistency of the QSU-Brief items in the present sample of $n = 39$ was high (α_{pre} =.90; α_{post} =.93).

Evaluation task

Task design of the evaluation and GNG training paradigm are based on work of Chen et al. (2016). During the experiment participants received two explicit evaluation tasks, one directly before and one directly after the GNG training. In the first evaluation task, participants were asked to evaluate 80 neutral pictures (i.e., neutral items, or people engaged in non-smoking behaviour) and 40 smoking pictures (i.e., smoking related objects such as a package of cigarettes, or people engaging in smoking behaviour). The smoking and neutral pictures in the evaluation task were matched on content, number of people in the picture, and sex. The evaluation task was self-paced, and participants could indicate how positive or negative they evaluated the pictures by using a 200-point slider ($-100 = negative$ and $+100 = positive$; the cursor started at 0). Participants first evaluated all neutral pictures and then the smoking pictures. The order of pictures within the smoking- or neutral category was randomized.

After the first evaluation task, both the 80 neutral pictures and the 40 smoking pictures were ranked from the highest evaluation to the lowest for each individual participant. The 40 neutral pictures and the 20 smoking pictures with the highest evaluations were selected. Of the 40 selected neutral pictures, 30 were randomly included as Go pictures in the GNG training. The remaining 10 selected neutral pictures were not included in the GNG training and served as Untrained Neutral pictures. Of the 20 selected smoking pictures, 10 were randomly included as No-Go pictures in the GNG training. The remaining 10 selected smoking pictures served as Untrained Smoking pictures. The selection was made in such a way that the average evaluations of neutral Go pictures and neutral Untrained pictures were matched for each participant, and the average evaluations of smoking No-Go pictures and smoking Untrained pictures were also matched for each participant (Chen et al., 2016).

After finishing the GNG training participants received the second evaluation task. This task was similar to the first task, with the adaptation that only the 40 neutral and 20 smoking pictures with the highest evaluations during the first evaluation were evaluated in the second evaluation task.

GNG training

The GNG training consisted of nine blocks, with six actual training blocks of 40 pictures (30 neutral Go, 10 smoking No-Go; thus a 75% Go/25% No-Go distribution) and three filler blocks (block 1, 4, 7). The filler blocks contained 20 unselected neutral pictures, namely the neutral pictures that received the lowest evaluations in the first evaluation task and were not evaluated at post-test. All filler blocks had the same Go/No-Go trial distribution as the six actual training blocks, thus participants had to go in 75% of the filler trials and to withhold their response in 25% of the filler trials. The first filler block served as practice block and the two other filler blocks were included to break the repetition of the other blocks (Lawrence, O'Sullivan, et al., 2015; Lawrence, Verbruggen, et al., 2015).

Each trial started with the presentation of a picture in the middle of the screen for 1000 ms. One hundred milliseconds after picture onset, a high (1000 Hz) or low (400 Hz) tone was played for 300 ms. The frequency of the tone indicated to the participants whether the picture was assigned to be a Go or No-Go trial. The frequency of the tone paired to Go or No-Go trials was counterbalanced across participants. Participants were instructed to press the spacebar on the keyboard as fast as possible in Go trials. If the picture was assigned to a No-Go trial, participants were instructed to not press any key until the picture disappeared. Intertrial intervals randomly varied from 1,500 to 2,500 ms, in steps of 100 ms. In each training block, the 40 selected pictures were randomly presented once, and since the whole training consisted of 6 training blocks, the total amount of training trials was 240.

Procedure

Participants in the smoking group were asked to refrain from smoking at least one hour before the start of the experiment. After participants gave informed consent, they were asked to fill out a battery of questionnaires. This battery consisted of demographic questions and smoking frequency and quantity questions. The FTND (Heatherton et al., 1991; Vink et al., 2005) to measure nicotine dependence, and the QSU (Tiffany & Drobes, 1991) to measure craving, were administered to explore their associations with the evaluations of smoking pictures. Participants in the non-smoking group did not fill out the complete smoking questionnaires, instead we asked them some smoking-related questions to check whether these participants did not smoke after all. Upon completion of the questionnaires, participants started with the evaluation task of smoking- and neutral pictures. Thereafter, participants completed a GNG training followed by the second evaluation task. The whole experimental procedure was implemented in PsychoPy (version v1.81.03; Peirce, 2007) and run individually for each participant on a Windows 7 computer. Finally, participants in the smoking group were asked to fill out the QSU again, to measure craving levels after exposure to multiple smoking pictures. At the end of the experiment, participants could choose whether they wanted to receive course credit or monetary compensation. All procedures were approved by the institutional review board at the Faculty of Social Sciences, Radboud University Nijmegen, The Netherlands (ECSW2015-2206-318).

Strategy of analysis

The average picture evaluation for each training condition (i.e., Neutral Go, Smoking No-Go, Neutral Untrained and Smoking Untrained), both pre- and post-training, was calculated for each participant. Then, to test whether changes in evaluations varied for different training conditions, repeated measures analyses of variance (ANOVA) were performed for smoking and neutral pictures separately. In the analysis of smoking pictures, the two within subject factors of interest were time (pre-training versus post-training) and training condition (Smoking No-Go versus Smoking Untrained), and the between subject factor was group (smokers versus non-smokers). Furthermore, correlations were computed to examine possible relations between the strength of the devaluation effect for smoking pictures and the severity of the smoking addiction. The correlations are discussed in the online supplementary materials. The analyses of the neutral pictures were similar to the smoking picture analyses, with the training condition comparing Neutral Go versus Neutral Untrained pictures. The neutral picture

Table 1. Performance on GNG training in total group, smokers and non-smokers.

	No-go accuracy	Go accuracy	Go RT (ms)
Total group	95.8% (0.5%)	99.1% (0.2%)	444.5 (7.5)
Smokers	96.2% (0.7%)	98.9% (0.3%)	450.8 (9.0)
Non-smokers	95.4% (0.6%)	99.4% (0.2%)	438.6 (11.8)

Note. Standard errors are between parentheses.

Table 2. Means and standard errors of all training conditions pre- and post-training and calculated difference scores.

	Pre-training	Post-training	Difference score
Total group			
Smoking no-go	−9.87 (4.33)	−28.11 (3.98)	−18.24
Smoking untrained	−9.69 (4.29)	−23.99 (3.97)	−14.30
Neutral go	41.17 (1.64)	35.41 (1.85)	−5.76
Neutral untrained	41.25 (1.66)	32.04 (1.94)	−9.21
Smokers			
Smoking no-go	18.38 (3.55)	−1.14 (3.47)	−19.52
Smoking untrained	18.17 (3.57)	2.76 (3.20)	−15.41
Neutral go	42.94 (2.37)	32.87 (2.54)	−10.07
Neutral untrained	43.09 (2.41)	31.94 (2.63)	−11.15
Non-smokers			
Smoking no-go	−35.50 (5.07)	−52.57 (4.31)	−17.07
Smoking untrained	−34.96 (5.02)	−48.25 (4.47)	−13.29
Neutral go	39.56 (2.26)	37.72 (2.66)	−1.84
Neutral untrained	39.58 (2.30)	32.13 (2.84)	−7.45

Note. Standard errors are in parentheses.

results are presented in the online supplementary materials, since they not concern our main hypotheses. Follow-up *t* tests with a Bonferroni correction for multiple comparisons for interactions were performed when necessary.

Finally, we expected that generally smoking pictures would be evaluated less positive than neutral pictures in both groups, but smoking pictures would be evaluated more positively by smokers than by nonsmokers. Therefore, we performed a repeated measures ANOVA to assess the differences in picture evaluation between neutral and smoking pictures between smokers and non-smokers. The within-subject factors were time (pre-training versus post-training) and picture content (average of Smoking No-Go and Smoking Untrained pictures versus average of Neutral Go and Neutral Untrained pictures), and the between subject factor was group (smokers versus non-smokers). Again, follow-up tests with a Bonferroni correction for multiple comparisons were applied when necessary. The data were analysed using SPSS 23 (IBM corp., 2015).

Results

Descriptive statistics

A summary of participants' overall performance on the GNG training is provided in Table 1. There were no significant differences between smokers and non-smokers on overall performance throughout the training. Table 2 provides all means, standard errors and difference scores for picture evaluations for the total group, as well as for

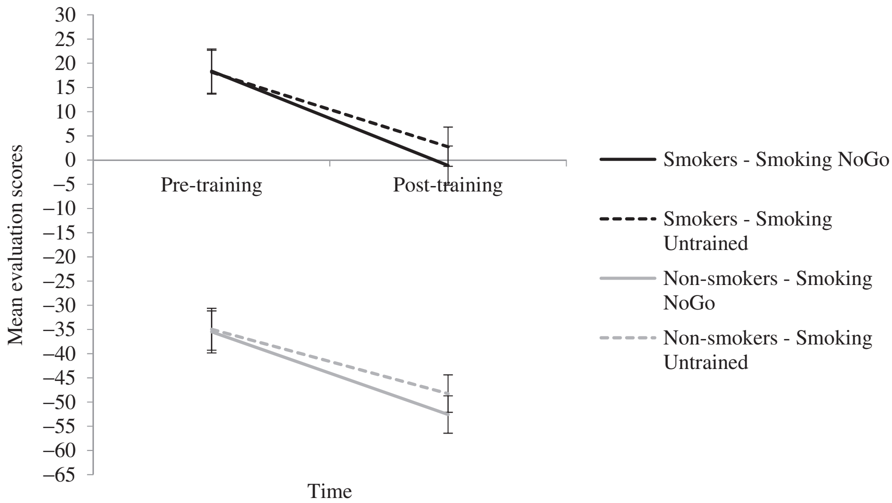

Figure 1. Mean evaluation scores and standard errors of smoking no-go and -untrained pictures over time for both groups.

the smokers and nonsmokers separately. Generally, all training conditions showed a decrease in evaluation from pre- to post-training.

Differences between training conditions

A repeated measures ANOVA was performed to test for differences between training conditions for smoking pictures. Significant main effects for time (F (1,80) = 74.70, $p < 0.001$, η^2 = 0.48), training condition (F (1,80) = 12.22, $p = 0.001$, η^2 = 0.13), and group (F (1,80) = 88.04, $p < 0.001$, η^2 = 0.52) were observed in analyses including smoking pictures. These results respectively indicated a significant decrease of evaluations over time, more negative evaluations of Smoking No-Go pictures than Smoking Untrained pictures, and more negative evaluations for non-smokers compared to smokers (for means and SEs see Table 2).

The interaction between training condition and time was also significant (F (1,80) = 10.12, $p = .002$, η^2 = 0.11), which can be interpreted as evidence for the devaluation of No-Go pictures compared to untrained pictures induced by GNG training. Follow-up t tests indicated that there were significant decreases from pre- to post-training evaluations for both Smoking No-Go ($p < .001$, η^2 = 0.50) and Smoking Untrained pictures ($p < .001$, η^2 = 0.41). Furthermore, the follow-up tests indicated no differences in evaluations between Smoking No-Go and Smoking Untrained pictures at pretraining ($p = .371$, η^2 = 0.01), but significant differences at post-training ($p = .001$, η^2 = 0.13; see Figure 1). Thus, although both No-Go smoking picture evaluations and Untrained smoking picture evaluations decreased over time, No-Go smoking pictures were evaluated less positively than Smoking Untrained pictures at post-training. The interaction between training condition and group (F (1,80) = 0.23, $p = .636$, $\eta^2 < 0.001$), and between time and group (F (1,80) = 0.36, $p = .548$, η^2 = 0.01), and the three-way interaction between training condition, time and group (F (1,80) = 0.02, $p = .896$, $\eta^2 < 0.001$) were not significant (see Figure 1).

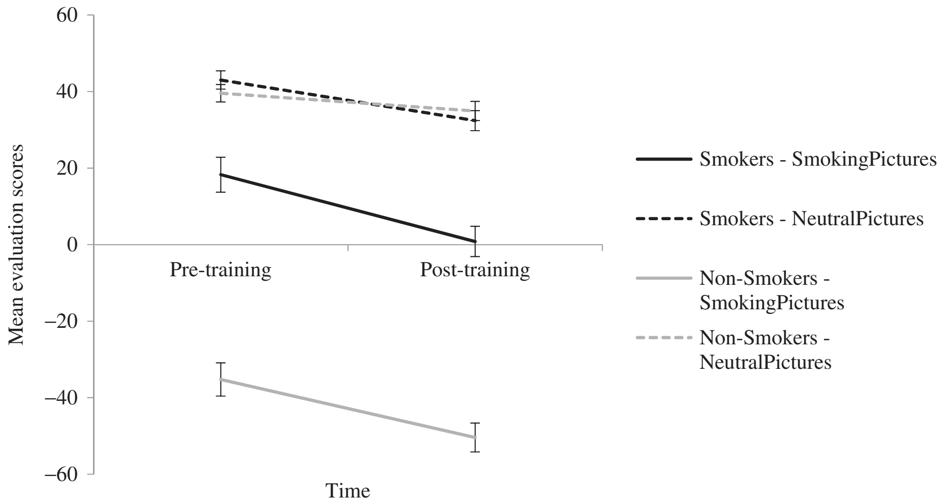

Figure 2. Mean evaluation scores and standard errors of smoking- and neutral pictures over time for both groups.

Differences in neutral and smoking picture evaluations between smokers and nonsmokers

A repeated measures ANOVA was performed with the within-subject factors time (pre-training versus post-training) and picture content (all smoking pictures versus all neutral pictures), and the between subject factor group (smokers versus nonsmokers) to assess the differences between neutral and smoking pictures within smokers and nonsmokers. Significant main effects were found for time (F (1,80) = 119.44, $p < .001$, η^2 = 0.60), picture content (F (1,80) = 273.68, $p < .001$, η^2 = 0.77), and group (F (1,80) = 63.32, $p < .001$, η^2 = 0.46). These results respectively indicate a decrease in evaluations over time, more negative evaluations of smoking pictures compared to neutral, and more positive evaluations for smokers compared to nonsmokers. In addition, the picture content and time interaction was also found to be significant (F (1,80) = 15.06, $p < .001$, η^2 = 0.16). Follow-up t tests revealed that both smoking picture ($p < .001$, η^2 = 0.48) and neutral picture evaluations ($p < 0.001$, η^2 = 0.35) decreased from pre-training to post-training (see Figure 2). Although both follow-up tests were significant, the effect size for the decrease in smoking pictures over time was larger than the effect size for neutral pictures (η^2 = 0.48 vs. η^2 = 0.35). This indicates a more pronounced decrease in evaluations for smoking pictures compared to neutral pictures. In addition, both at pre-test ($p < .001$, η^2 = 0.73) and post-test ($p < .001$, η^2 = 0.77) neutral pictures were evaluated more positively than the smoking pictures.

Furthermore, the interaction between picture content and group was also significant (F (1,80) = 62.93, $p < .001$, η^2 = 0.44). Additional follow-up analyses indicated that both smokers ($p < .001$, η^2 = 0.31) and nonsmokers ($p < .001$; η^2 = 0.80) were less positive about smoking pictures than about neutral pictures. Nevertheless, smokers were more positive about smoking pictures than nonsmokers ($p < .001$, η^2 = 0.52), while such a difference between smokers and non-smokers was not found for neutral pictures ($p = .889$, η^2 < 0.001; see Figure 2). Finally, the interaction between time and group (F (1,80) = 3.55, $p = .063$, η^2 = 0.04), and the three-way interaction between picture content, time and group (F (1,80) = 0.68, $p = .412$, η^2 = 0.01) were both not significant. Thus, smoking pictures were evaluated less positively than neutral pictures by both smokers and nonsmokers. In addition, smokers evaluated smoking pictures more positively than the nonsmokers.

Discussion

As expected, we found that smokers showed a devaluation effect after a smoking-specific GNG training, suggesting that the evaluation of smoking cues can be decreased by means of GNG training. This is in line with previous research, that found this same effect after a food-specific- or alcohol-specific GNG training (Chen et al., 2016; Houben et al., 2011, 2012; Lawrence, O'Sullivan, et al., 2015; Veling et al., 2013a, 2013b). These results support our theoretical idea that GNG training could serve as a trans-diagnostic mechanism of change, and thereby could be a potential target for intervention of multiple problem behaviours. In addition, smoking pictures in general were evaluated less positively than neutral pictures by both smokers and nonsmokers. Importantly, we were able to diminish evaluations of smoking pictures also among nonsmokers. This pattern of findings suggests that it might be possible to extend the potential of GNG training from intervention to prevention. Although promising, replication investigating these prevention possibilities is warranted.

In a first attempt to investigate the effects of a smoking-specific GNG training, the current research replicated devaluation results from food- or alcohol-studies. This adds to the already existing evidence for the BSI-theory, but it does not fully clarify the interacting working mechanisms of GNG training on behaviour. As laid out in a review by Veling and colleagues (2017), there are multiple accounts that could theoretically explain the effects of a GNG training on behaviour. They describe either (1) a top-down account, whereby training strengthens inhibitory control toward No-Go stimuli; (2) an automatic bottom-up account, in which training creates automatic associations between No-Go stimuli and stopping responses; and (3) a devaluation account, where training leads to devaluation of No-Go stimuli (Veling et al., 2017). According to the review, empirical evidence is only available for the devaluation account, while the other accounts having not been experimentally tested yet (second account) or only have been tested once (first account; Adams et al., 2017). To advance this line of research, and to be able to make substantiated claims about the working mechanisms of GNG training, we recommend the inclusion of multiple outcome measures (e.g., Go/No-Go task, evaluation task, behavioural outcome etc.), well-powered studies and the analysis of mediating mechanisms of change.

In the current study, lower evaluations of trained No-Go pictures compared to untrained pictures were interpreted as evidence for devaluation. This definition was chosen based on previous work (Chen et al., 2016), and allows us to exile the explanation of regression to the mean for our results. Yet, central to considering the impact of a GNG training as intervention or prevention tool is the issue of generalization from trained to untrained stimuli. Generalization of the effects to other related stimuli is critical when behaviour change is the end goal; the individual needs to transfer the learned associations to stimuli in their environment. In the current study we indeed found significant decreases in evaluations of untrained smoking stimuli which, however, were smaller than the decreases in trained smoking stimuli. These decreases in untrained smoking stimuli can be caused by two possible explanations. First, it could merely be a case of regression to the mean (Cohen, Cohen, West, & Aiken, 2013). Note that regression to the mean may occur for both trained and untrained pictures, because we selected the most positive pictures based on the pre-measure. Second, it could be that, in addition to regression to the mean, some transfer of devaluation from the trained pictures to the untrained pictures may have occurred (Chen et al., 2016). However, our data do not allow us to address this explanation, because this would require a between-subjects condition with no training.

Based on our results in combination with the results in the food- and alcohol domain, we can cautiously argue that GNG training leads to decreased perceived attractiveness of substance-related stimuli. That in turn may weaken impulses toward these stimuli, thereby making individuals less likely to approach substance-related stimuli and better able to inhibit their responses, which in turn could lead to behaviour change (Veling et al., 2008, 2014). These promising results call for follow-up studies that investigate the possible effect of GNG training on (smoking) behaviour, with a particular focus on the working mechanisms underlying the effects of GNG training, the possibility of transfer of effects from training to the real-world context, and the opportunity of GNG training as prevention tool.

For future studies attempting to bring GNG training to an intervention context it is important to consider the multi-determinant nature of smoking. Smoking cessation is difficult to reach and there are many components influencing this process. For example, motivation to quit is an important predictor of intervention success and should therefore be included in future studies testing the effect of GNG trainings on smoking behaviour. Furthermore, comprehensive interventions are considered necessary for effectiveness. Previous research has shown that the complex interventions, including multiple mechanisms of change, are most effective (Fanshawe et al., 2017). A possible add-on to GNG trainings is attentional bias modification (ABM), in which the attention of participants is trained away from the targeted stimuli (i.e., smoking pictures) and towards neutral or control stimuli. Studies have shown some promise of ABM in the alcohol (Wiers, Boffo, & Field, 2018) and smoking (Elfeddali, De Vries, Bolman, Pronk, & Wiers, 2016) domain, but the combination of GNG and ABM training seems more effective in boosting intervention effects (Stice, Yokum, Veling, Kemps, & Lawrence, 2017; Wiers et al., 2018). In these kinds of interventions, participants are trained towards healthy behaviours (such as healthy food) by ABM, and trained to not respond to unhealthy behaviours (such as snack foods) by GNG training.

Finally, future intervention studies would benefit from incorporating objective measures to examine smoking behaviour, instead of only relying on self-report. Previous studies have included measures of smoking topography, carbon-monoxide (CO) levels in breath, or cotinine levels in blood, saliva, urine, or hair as a proxy of smoking behaviour (Deveci, Deveci, Açik, & Ozan, 2004; Florescu et al., 2009; Lee, Malson, Waters, Moolchan, & Pickworth, 2003). In addition, ecological momentary assessment (i.e., the repeated real-time assessment of behaviour in participants' natural contexts) could be another method to capture smoking patterns not measured by questionnaires or retrospective data (Shiffman, 2009).

Limitations and recommendations

One important methodological limitation is that we did not include an extra smoking participant group, that did not perform the training as a (non-)active control group (Boot, Simons, Stothart, & Stutts, 2013). Instead, we included a non-smoking sample, which provides valuable information about the effects of a smoking-specific GNG training on nonsmoking participants. The inclusion of another group of smokers as control group would be important to test possible transfer effects from No-Go stimuli toward untrained stimuli. In addition, we only included an explicit evaluation measure in our study to test for devaluation. Future studies would benefit from including an implicit evaluation measure (e.g., Implicit Association Tasks; Greenwald et al., 1998) as well, to allow for a direct comparison between these two types of measures and mediation of effects on smoking outcomes.

Furthermore, we have two recommendations for further research and for optimisation of the training itself. First, the inclusion of one session of GNG training only allowed us to examine very short-term effects. While a single session of GNG training already leads to a robust reduction in food and alcohol consumption, the effects of a single session may not persist over time (Allom et al., 2016; Jones et al., 2016). Therefore, the inclusion of multiple training sessions and longer-term follow-up measures is warranted. However, there are limitations to multiple training sessions as well: the current training could be perceived as relatively unengaging as it is very repetitive (Beard, Weisberg, & Primack, 2012; Boendermaker, Boffo, & Wiers, 2015; Brosan, Hoppitt, Shelfer, Sillence, & Mackintosh, 2011).

An elegant solution for balancing these issues might be to improve the design of the training context by using video games, especially for a younger age group (Forman et al., 2017). Thus, a second recommendation is to transform the GNG training into a video game, which can not only deal with potential problems of motivation, but also with the repetitive nature of these trainings (Forman et al., 2017). Video games are a ubiquitous part of our current society (Granic, Lobel, & Engels, 2014), and are able to harness young people's intrinsic motivation to playfully engage with training regimens (Ryan, Rigby, & Przybylski, 2006). Furthermore, video games can encourage repetitive gameplay without boring participants through the use of reward systems, novel elements, and social learning mechanisms (Granic et al., 2014; Green & Bavelier, 2012).

Conclusion

This study showed that smoking-related cues can be devaluated in smokers and non-smokers by means of a GNG training. These results are the first to show this among smokers, and suggest that the same mechanisms are at work among smokers as among individuals who eat unhealthy or who consume too much alcohol. This work adds to the already existing evidence for GNG training, and is a necessary initial step towards establishing the working mechanisms driving the effects of this training.

In future research, it will be important to determine the theoretical underpinnings of GNG training, and the application of technological innovations to optimize future intervention efforts of problem behaviours such as smoking.

Data availability statement

The authors confirm that the data supporting the findings of this study are available within the supplementary materials.

Disclosure statement

No potential conflict of interest was reported by the authors.

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